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KEYBOARD AND MESSAGE EVALUATION FOR COCKPIT INPUT DATA LINK

E. H. HILBORN
TRANSPORTATION SYSTEMS CENTER
55 BROADWAY
CAMBRIDGE, MA. 02142

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16. Abstract

The project reported herein studied some methods for implementation of the man-machine interface of Digital Data Link for Air Traffic Control. An analysis of information transfer requirements indicated that a vocabulary of less than 200 words could yield meaningful messages for all routine ATC transactions. Keyboard configurations suitable for one-handed operation to yield alphanumeric outputs were studied and a ten-key character selection layout based upon sequential keying of the first two letters of the phonetic alphabet was developed. Tests with experimental subjects indicated that training time was no longer and keying proficiency at least as good as that achieved with the larger keyset suggested by ARINC.

A second order mnemonic coding scheme based upon key letters of the words of messages was proposed as a means for reducing the number of required keystrokes to generate such messages.

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COCKPIT INPUT AND DISPLAY DEVICES FOR DATA LINK

INTRODUCTION

The introduction of digital data link for air-ground communication will make possible, and in some cases will require, changes in the man-machine interfaces in the communications system. Some transactions presently performed by voice will be carried out in the future via visual displays and manual controls. This change of input/output media could have both positive and negative effects on the user's workload. An important task is the human factors work to anticipate and evaluate the impact of these changes.

Digital Data Link techniques can provide an attractive solution to the problem of the present air-ground communication system overload. Since the hardware to implement a Data Link requires little or no extension of existing technology, the problem becomes one of gaining user acceptance. Unless the man-machine interface is so designed as to reduce rather than to increase user workload, microphones will continue to be the preferred means for information transfer.

Regardless of the nature of the intervening data transmission system, the pilot (or some other aircrewman) must receive the information conveyed by the transmission in an intelligible form, and he must also be able to enter information into the system in such a way that it can be accurately encoded for transmission back to the ground. Earphones and microphones are the I/O devices presently employed at the pilot/system interface, and hearing and speech are the human performance modes employed with these devices.

A digital data link system interface with the pilot could be designed via two alternative approaches:

1. A visual display for incoming information and a manually operated keyboard for entering outgoing information.

2. A speech synthesizer to convert incoming digital data into simulated speech and a speech analyzer to convert spoken messages to digital codes for outgoing transmission.

Each of these possible approaches has both advantages and disadvantages. Approach (1), display/control system, employs well-developed technology widely used for other purposes and readily adaptable to the present use. However, this wide usage is its principal drawback. While communicating, the pilot will

often be observing a large number of other displays, and manipulating many other controls in the operation and navigation of his aircraft. His eyes and hands are so busy that we may risk deteriorating his total performance by substituting still another set of eye/hand tasks in place of traditional ear/voice tasks. If we take this risk, then we must aim to minimize it through the optimization of the design of the I/O equipment for human performance.

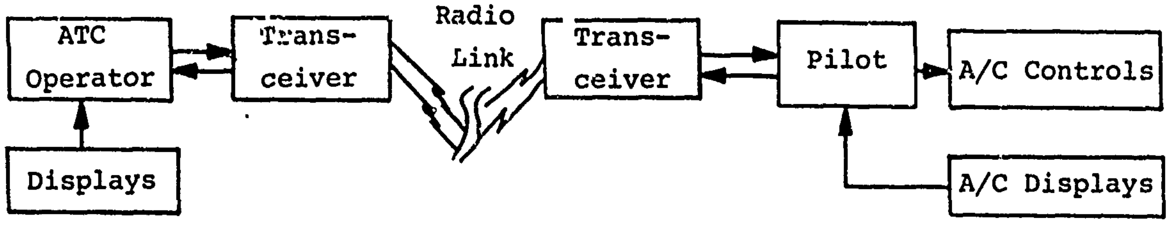
The advantage of approach (2) speech synthesis and analysis, is that it would preserve the present mode of communication for the pilot, requiring a minimum of adaptation to new modes of communication, and would not add another burden to the eyes and hands. The disadvantage of this approach is that it employs a technology that lags far behind display/control methods in development and application. An evaluation of the state-of-the-art in speech synthesis and analysis must precede further consideration of its application to air-ground communications.

The project being reported here began the process of exploring these alternative approaches in depth. Consideration of approach (1) led to studies of the minimal vocabulary needed to convey ATC information and to the experimental evaluation of a message-coding and entry technique, including alternative keyboard layouts. Consideration of approach (2) led to a decision to buy and evaluate a speech synthesizer; speech analysis was not judged ready for application.

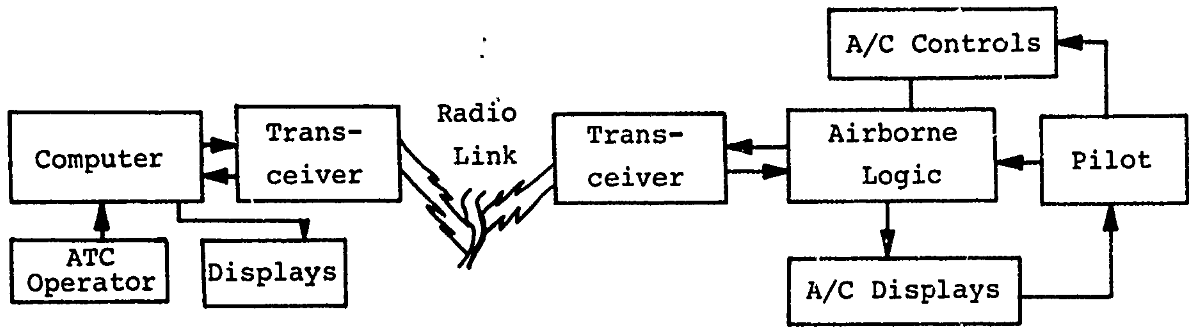
The balance of this report describes these studies and experiments in detail.

INTERIM SYSTEM CONCEPTS AND DEVICES

Block diagrams of systems, while useful in depicting system relationships, as in Figure 1, provide little in the way of information as to system complexity. Thus, the present air traffic control system might be depicted simply as:



With equal simplicity, a future completely automatic system could be depicted as:



In order to provide a means for systematic discussion of concepts for improving the present system (improving in this context meaning reducing user workload and increasing system reliability and safety while controlling increasing traffic flow), it is necessary to provide a more elaborate block diagram, as depicted on the next page. It should be emphasized that not all portions of this system require concurrent implementation; instead, options exist as to which might be included and in what time frame.

One important point should be made at this time. Certain of the possible approaches provide outputs which identify the input as human operator-derived. Others, even though derived from human input can provide an output similar to that of a computer. Appropriate use of such intermediates can play an important role in gaining acceptance of an eventual all-automatic system since the receiver of the information can at no time be sure of the amount of automation being employed. Information can continue to be provided to him in the same manner he has grown accustomed to during semi-automatic operation of the system.

We are now in a position to discuss techniques for information interchange as they apply to a semi-automatic system. Information interchange, in turn, can be subdivided into (1) means for information entry into the system, (2) method of transmissions, and (3) information outputs to the operator.

Information Entry

Although keyboards are presently used extensively along with voice for information interchange among ground-based facilities, air-ground-air communications conventionally utilize

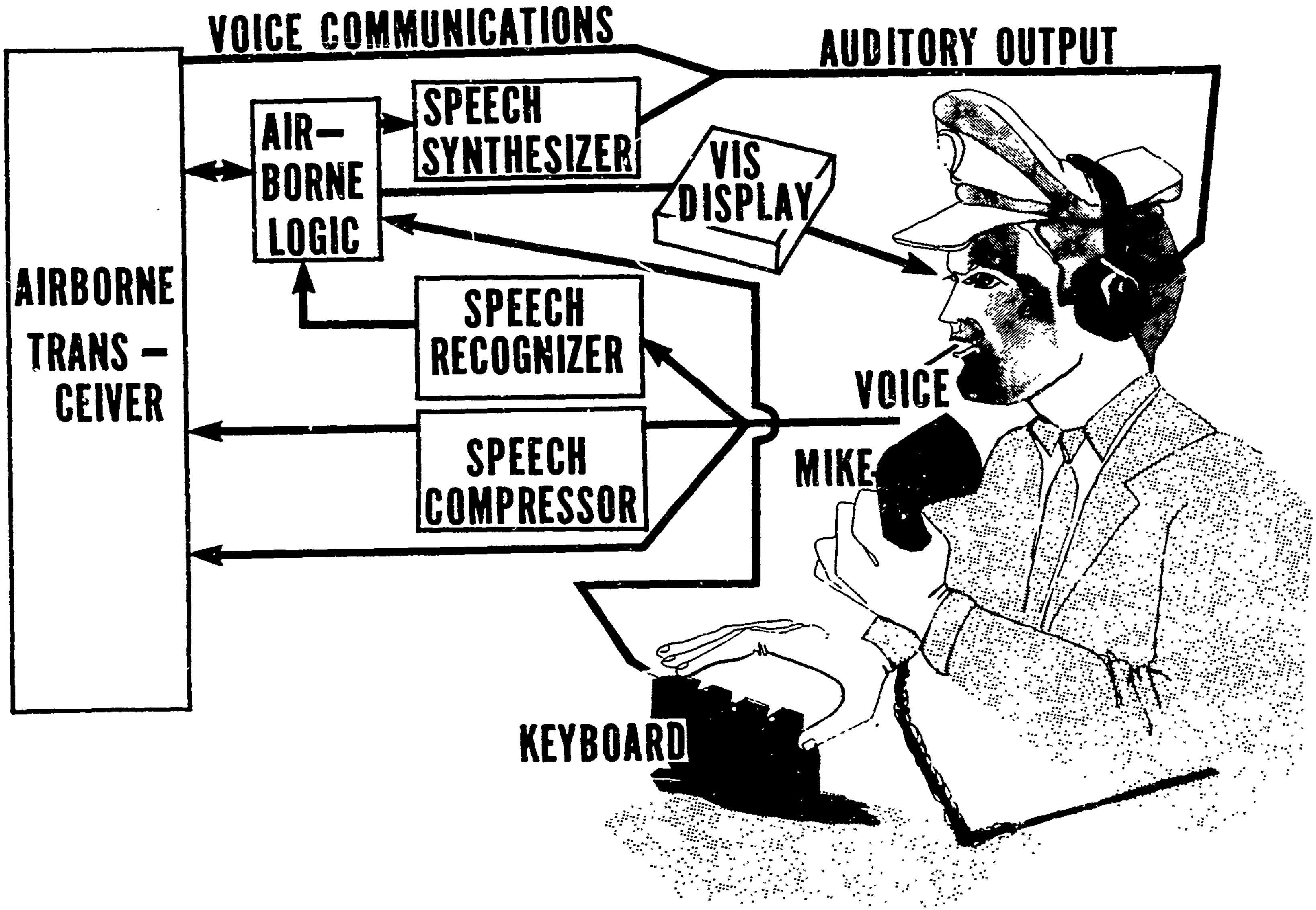

VOICE COMMUNICATIONS
AUDITORY OUTPUT
AIRBORNE TRANS - CEIVER
AIR-BORNE LOGIC
SPEECH SYNTHESIZER
VIS DISPLAY
SPEECH RECOGNIZER
SPEECH COMPRESSOR
VOICE
MIKE
KEYBOARD

Figure 1.

microphones for information entry. Before blithely attempting to eliminate this practice, due consideration should be given to possible means by which it may be continued. Speech recognition equipment, for example, with subsequent digitizing of the vocabulary, could reduce communication system overload without requiring retraining of personnel. The present state-of-the-art of speech recognition equipment may permit this to be accomplished in the foreseeable future. A few years ago such equipment could be programmed to recognize only the digits zero thru nine when spoken by a single voice. Further improvements were made to allow such equipment to be programmed to adapt rapidly to any one voice, and at present, certain devices can recognize with high accuracy such a digit list when spoken by any of a number of voices.

Development of speech recognition equipment with a reasonable vocabulary is dependent upon the time, money and effort expended and, without knowledge of future R&D funding in this area, no reasonable time frame for equipment availability can be predicted. Therefore, other means for information entry into the system were examined and keyboards appeared to offer the only immediately available solution. Such possibilities as single-button keying (Morse Code), chord keying (Stenotype), standard typewriter keyboards, and limited keysets (for one-handed operation), were investigated and it was concluded that some version of the limited-key set would offer the best compromise between entry speed and operator training time. Three varieties of such limited-key devices have accordingly been fabricated and preliminary evaluation of these is reported in the section "Keyboard Studies".

Method of Transmission

A reasonable figure at which words can be spoken and recognized with high accuracy is approximately 200 words per minute. In contrast, digital transmission over a 2400 bits per second system permits approximately 3,400 words per minute, an improvement by a factor of more than 17 (using the ICAO seven-unit code without parity). There is, therefore, no question as to the superiority of digital over other transmission means, provided the problem of digitizing the input can be overcome. Other, less efficient solutions can, however, eliminate the digital entry problem.

At the lower extreme in terms of transmission efficiency, techniques for temporal clipping of speech exist. The high redundancy in speech patterns allows millisecond portions to be deleted regularly without recognizable impairment of recognizability. This solution is, however, somewhat insignificant since

the amount of possible compression is strictly limited. Real-time transmission is also precluded since the information must be recorded, clipped and then transmitted.

With the bandwidth available on VHF communications channels, other solutions are possible. Tape recording, with playback at higher tape speeds is possible. Actual ATC transactions have been recorded in the TSC laboratory, played back at four times their normal speed, recorded, and then played back at one-fourth speed with no noticeable impairment in voice recognizability. Thus, a simple loop of tape, with means for varying the tape length between recording and playback heads, could reduce eight seconds of speech to two seconds of transmission, and similar equipment working in an opposite manner at the other end of the system could restore the voice to its normal speed and frequency. Again, we are faced with the matter of non-real-time transmission.

Information Outputs

The use of digital transmission makes possible the use of a variety of visual techniques for displaying information, and several of these can provide good readability even in the presence of direct sunlight. ATC information has, however, traditionally been conveyed auditorially and caution should be exercised when considering the use of only visual displays for presenting digitally transmitted information. Flybar and similar systems for the presentation of flight control information were less than successful because of the burden which they placed on auditory perceptual channels. Similarly, the presentation of ATC information solely by visual means could overburden the already busy visual channels of the pilot. A suitable compromise would appear to be that of supplying ATC information in both auditory and visual form. This provides the immediate awareness inherent in the use of an auditory signal with the more permanent record available from a visual display. Present techniques for synthetic speech generation by solid state means makes this possible even when the only input signal to the system is a digital code.

Summarizing, the interim techniques which presently offer the best possibilities for handling increasing traffic flow while reducing operator workload are those which handle information digitally in the same manner as that which may later be provided by a computer. Their adoption at this time can provide a smooth transition into later systems emphasizing computer control with manual over-ride only in the event of system failure.

MESSAGE TRANSACTION ANALYSIS

Analyses of ATC transactions have been performed many times previously and unexpected results during this study were neither predicted nor obtained. The study was, however, deemed necessary as part of this project (1) to acquaint the investigator with ATC procedures, (2) to assure that any data obtained was representative of current procedures and problems, and (3) to assure that presently used vocabulary was being recorded and studied.

With this in mind, a two-pronged approach was employed, subjecting reasonable amounts of data to a relatively comprehensive analysis, supplemented by more casual listening to many hours of transactions in order to develop a vocabulary by selection of useful words not used with great frequency. The efficiency of this procedure was enhanced greatly by the use of a tape recorder with separate record and playback heads and a voice switch which turned on a second recorder during periods of conversation. The delay between recording and playback heads of the first machine allowed the second machine to come up to speed prior to the time that it was to record. This not only saved hours of time which would have otherwise been spent in listening to periods of silence, but also provided some data as to the degree of voice channel utilization. For those periods where false triggering of the voice switch by static and other forms of interference was minimal, a reasonably straight line relationship existed between channel utilization time and number of transactions per hour. This would seem to indicate that saturation of the system would occur with approximately 300 transactions per hour if present vocabulary and procedures are maintained. During busier periods, however, two procedural changes occur. Firstly, multiple transactions, particularly heading, speed and altitude changes, are combined within one message. Secondly, information and advisories such as weather reports become progressively more fragmentary. Thus, during one of the hourly periods studied, a total of 314 transactions occurred. At the same time, these data indicate that the existing system has reached or certainly approaches saturation during peak periods, and that improvements in the system are sorely needed.

Some immediate improvement might be obtained by certain controllers changing their choice of terminology. The phrase, "Eastern 123; descend and maintain 3 thousand" could be abbreviated to "Eastern 123; descend to 3" without loss of information and with some savings of time. Commercial pilots for the most part are reasonably careful in their choice of terminology and brief in their communications. This cannot be said for the general aviation pilot, and some training in this respect as part of their licensing procedure could free air time for more useful purposes.

As suggested earlier, the message content analyzed in this study shows no surprising departures from that of previous reports. During slack periods, the percentage of non-routine messages increases somewhat, since pilots may feel inclined to ask such personal things as, "Is (controller's name) on duty?" During peak periods in the data of this study, the percentage of non-routine messages was less than 3%. The remaining 97% can be neatly divided into several categories whose relative percentages vary most noticeably with the weather and the controller. Thus, during good visibility, traffic alerts are frequent, whereas during low visibility such information is useless to the pilot and is therefore not transmitted. Psychologically, however, this procedure is extremely sound. If the pilot knows that during good weather, a controller in a windowless room can advise him of nearby traffic before he himself sees it, he can have confidence to proceed thru bad weather knowing that the controller is keeping him out of conflicts.

The second factor relating to message category variability, that of the controller, is a function of his individual preference in techniques for varying the amount of control exercised by altitude, speed and heading changes, all of which can be used interchangeably under many circumstances.

Despite these variabilities, some effort must be made to categorize the average air-ground transaction in order to permit the relating of verbalization speeds to the keying speeds obtained with the keyboards described and evaluated in the section "Keyboard Studies" of this report. Previous studies suggested techniques for mnemonic coding of routine messages so that they could be easily remembered and could be entered with a minimum number of keystrokes. Using these techniques and what is hopefully a reasonable categorization of relative frequency of standard air-ground messages, resulted in the following table:

	Relative Message Frequency	Mean Number of Keystrokes	Factor
Acknowledgement	.50	2	1.0
Initial Contact	.15	3	.45
Traffic (not) located	.10	5	.50
Weather info. request	.03	3	.09
Retransmission request	.02	2	.04
Mean keystrokes per message			2.28

Timing data supplied by NAFEC along with their transcripts of New York Center and Philadelphia Tower transactions indicated that the average reply by a pilot consumes approximately three

seconds. Thus, if on the average a pilot could enter 2.3 keystrokes on a keyboard in 3 seconds, the use of such a keyboard should not increase his workload.*

This project made a start toward the development of a basic vocabulary for ATC communications and, although extensions and refinements of this list have been made, it should still be considered only tentative. Thoughts which may be expressed in a variety of ways can have varying degrees of interchangeability as shown in the following examples:

if able = if feasible
ascend = climb
above = over
descend = dive
down = below
leave = depart
do you = what is = say = can you = question?
follow = stay behind = remain behind
stand by = wait
yes = affirmative = you may = roger = acknowledge
no = negative
delay = hold
advise = report = inform
report to = contact
end = terminate
change to (freq) = contact on
to = toward
squawk = ident
airport = field
proceed = continue
start = begin
how about = may we = permission to?
in sight = located = see
reduce to = slow to
now = presently
land on = use
repeat = say again
expect = await = anticipate
further = next
if = when

The reader is encouraged to analyze, critique and extend this list bearing in mind that words may be defined and redefined to indicate what they are intended to mean. Thus, for example, in the aeronautical sense, a dive usually indicates a

*A reasonable assumption is made here that the pilot would need to enter his aircraft identification only once per flight, and henceforth it would be transmitted automatically as part of the message.

very sudden descent. To the submariner, a dive is a normal descent, modified under certain circumstances by the term "crash dive". Aviation parlance itself has introduced such potential ambiguities. The term "Boston altimeter is ---- " is universally accepted, even though completely incorrect technically. It is used to indicate the barometric pressure or the altimeter *setting* for calibration.

The development of a definitive word list based upon alternative ways of conveying the same information is a basic prerequisite to the development of hardware to permit digitally transmitted synthetic speech to be used in the ATC environment. Many of these words are listed in the FAA Enroute and Terminal Air Traffic Control manuals, the Airman's Information manual and ICAO Annex 10, Vol. II.

Such vocabulary limitations are assuredly necessary if cost-effective hardware for synthetic speech is to be possible. Fortunately, most of these restrictions do not impose severe changes from present terminology. The use of local landmarks as descriptive fixes is, of course, ruled out, but these can easily be replaced by designating bearing and fix from a VOR. Airline names need not be included in the vocabulary since they have already been assigned two-letter abbreviations: thus, "American" becomes "Alfa-Alfa". Aircraft types similarly have abbreviations, and no constraints on the vocabulary would be imposed providing that it included numerals and the ICAO phonetic alphabet.

An interim bare-bones vocabulary is listed below:

acknowledge
affirmative
again
ahead
Alfa
altimeter
altitude
and
approach
at
back
base
beacon
behind
below
bound
Bravo
break
by
cancel
center
ceiling
Charlie
clear
climb
clouds
confirm
contact
continue
control
correct
correction
course
dash
Delta
depart
descend
destination
direct
down
east
Echo
eight
emergency
estimated
expect
fast
feet
five
flight
fog
follow
for
four
Foxtrot
frequency
from
further
go
Golf
ground
half
heading
hear
hold
Hotel
how
IMC
ice
if able
IFR
in
increase
intended
intermittent
India
-ing
Juliett
Kilo
knots

left	out	six	turn
level	over	slippery	Uniform
light	Papa	slow	unrestricted
Lima	Quebec	slower	up
maintain	question	snow	use
marker	radar	south	verify
me	rain	speak	Victor
Mike	range	speed	visibility
miles	read	squawk	VFR
minutes	ready	stand	VMC
near	request	start	VOR
negative	remain	Tango	weather
next	repeat	take	west
niner	report	taxi	Whisky
north	restriction	thank	wilco
November	right	that	wind
now	roger	three	words
of	Romeo	time	X-ray
off	runway	to(two)	Yankee
on	RVR	tower	you
one	say	traffic	zero
or	seven	twice	Zulu
Oscar	Sierra	turbulence	

Even though this list does not necessarily represent the ultimate choice of words in preference to their synonyms or words least likely to be confused with each other when heard, it does permit, although somewhat ungrammatically, conveying the more common ATC information. Mensuration units are omitted since these can be determined by context or convention. Thus, RVR might be followed by "three zero zero zero" or by "one half" with no confusion that one expressed feet and the other miles. Similarly, heading is always expressed in degrees, speed in knots and delays in minutes.

Summarizing; the content of ATC transactions can be conveyed with a vocabulary of limited length. Standardization of this vocabulary to avoid words likely to be confused could lead to increased transmission efficiency and reduced errors of interpretation, and could prepare personnel for the eventual use of digital transmission of synthetic speech using the same vocabulary.

KEYBOARD STUDIES

Some time ago consideration was given to the use of a Bell Touchtone Keyboard modified by the addition of extra keys at the bottom to permit selection of the desired letters or numerals on each key. This keyboard is depicted in Figure 2. While

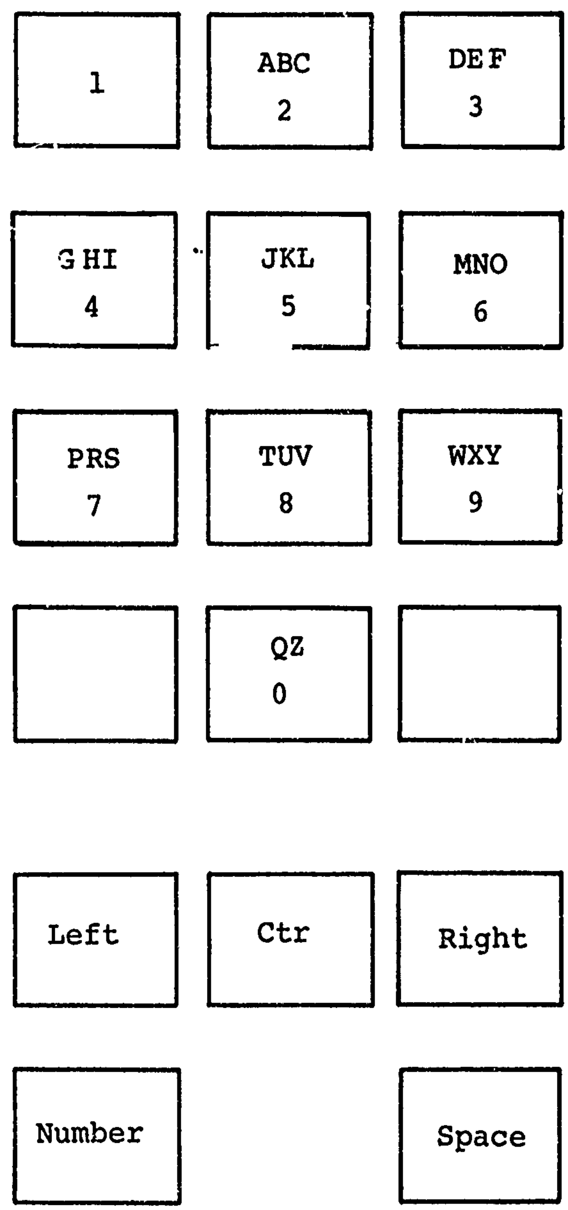


Figure 2. Modified Touchtone Keyboard

this concept offered the obvious virtue that it could be used immediately by untrained personnel, it appeared less than ideal from a human factors aspect. The requirement for keys arranged in six rows vertically exceeded capacity for operation by mere finger movement; instead, forearm motion was also required. Additionally, even though three fingers might be used, approximately one-third of the keystrokes required hurdles; that is, motion of one finger over one or more intervening keys in order to specify a desired letter or numeral. Thirdly, the concept was not amenable to mnemonic coding as a means for simplifying the callup of standard messages in a manner which would reduce the number of keystrokes required; instead, the user was forced to memorize a list of numerical equivalents of such standard messages.

These deficiencies of this concept dictated that other input keyboard configurations should be investigated. Two layouts based upon the use of sequential double-keying of the first two letters of the words of the ICAO phonetic alphabet as a means for letter selection were designed and fabricated. The keyboard effort has accordingly been directed toward using this as a part of an encoding scheme for Data Link. With proper selection of combinations of alphas on individual keys, the first two letters of the words used in the ICAO code can yield unique combinations. Since "foxtrot", "golf" and "hotel" all have the same second letter (and other similar situations occur with other letter combinations), the assignment of three sequential letters to each key in the manner of the Bell Touchtone Keyboard precludes this sort of coding. However, since airline pilots and ATC personnel are already completely familiar with this alphabetic representation, further exploration of the concept seemed warranted. For example, keys might be allocated as follows to yield non-redundant coding for individual alphas:

Key	Alphas	Numerical Equivalents
1	ABC	16, 18, 14
2	DEF	22, 21, 27
3	G	37
4	H	47
5	IJK	57, 59, 55
6	L	65
7	MNO	75, 77, 78
8	PQRS	81, 89, 87, 85
9	TUV	91, 97, 95
0	WXYZ	04, 08, 01, 09

The coding scheme used above immediately permits the elimination of the three keys required in the modified touchtone concept for specification of "right", "center" and "left";

permits the generation of any unique alpha without increasing the number of key activations required, and permits a more compact keyboard, with resulting decrease in the requirements for hand travel.

The above thus utilizes 26 of the 100 possible two-digit combinations as follows:

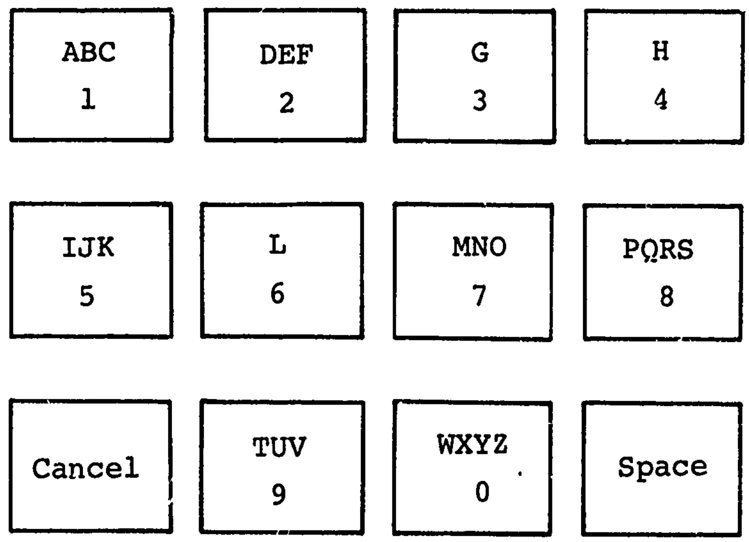
	Second Digit									
	0	1	2	3	4	5	6	7	8	9
0		X			X				X	X
1					X		X		X	
2		X	X					X		
3								X		
4								X		
5						X		X		X
6						X				
7						X		X	X	
8		X				X		X		X
9		X				X		X		

By the use of reasonably simple digital logic, it is possible to specify that each of these two digit combinations should result in the display and later transmission of a single alpha. However, by utilizing similar logic, other unique two-digit combinations can result in the transmission of two alphas which can be useful in a mnemonic coding scheme. Thus, standard messages may be encoded without too great departure from the vocabulary in use. For example:

Ground to Air	Air to Ground
02 = WE- Weather (provides automatic transmission of weather information.)	Request for weather info.

The two layouts differed only in that one utilized a four by three array to permit four-finger operation, while the other used a three by four array as depicted in Figure 3. Examination of this latter concept was necessary because the human factors literature failed to provide any data concerning typing errors which might be attributable to the little finger. On either keyboard numerals may be entered by depressing the appropriate key plus the space key.

A working model of the modified touchtone keyboard was also constructed. Logic circuits for the three keyboards were assembled and a preliminary evaluation was made.



4 x 3 Matrix

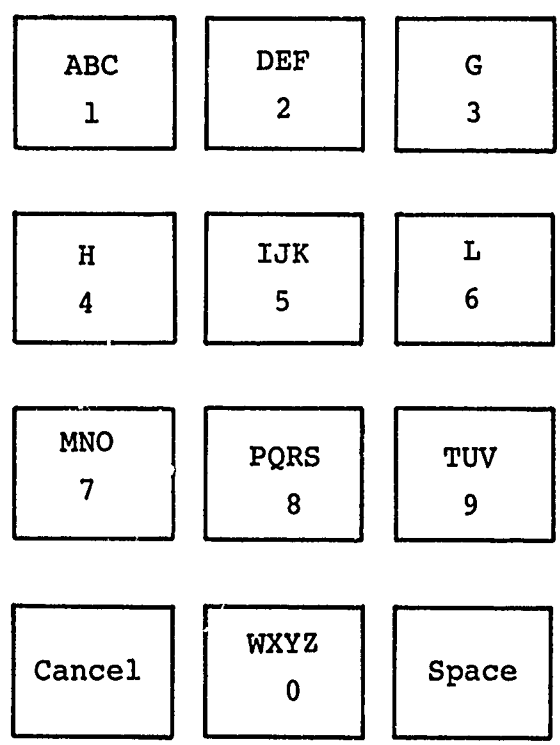


Figure 3. Keyboard Matrices

For experimental subjects, it was decided to use patients and corpsmen on the orthopedic ward at the local Naval hospital, under the assumption that if this group could learn to operate keyboards consistently with a relatively short training period, (without any specialized training), it should be safe to assume that airtraffic controllers would adapt to using this equipment quite readily.

An initial group of nine subjects, all volunteers, completed the full 20 hours of training. The mean age of the group was 23 (range 18 to 35). Mean education level was 11.9 years (range seventh grade thru four years of college). At the start, all professed some knowledge of the phonetic alphabet, although none acknowledged automatic proficiency in its use. Physical disabilities of the group included a total of six broken legs (including three in traction), and two broken arms (neither involving the preferred hand). As might be anticipated, this forced certain of the subjects to use their keyboard in less than ideal positions, which could only lend additional credence to the data obtained. Seven of the subjects were right handed; two were left handed. All practiced using their preferred hand. Each subject worked with only a single keyboard, and keyboard assignments were made by lot. In order to promote touch typing, the keys were identified only by numerals thereon; each subject was given a chart indicating the letter combinations on each of the keys of the keyboard.

The complete training schedule for a subject consisted of forty 25-minute sessions, with the remaining five minutes of each session accounted for by equipment setup and removal time. No scoring was attempted during the first two sessions; instead, the subjects were given individual instruction as to the double-keying principles involved in letter selection and obtained initial familiarization with the keyboard layout and keying action. Subjects were urged to use multiple fingers appropriate to the keyboard layout, but this was not an absolute requirement.

The output from the keyboard logic consisted of the standard seven-bit ASCII code suitable for running a variety of printing devices. For portability, a Strip Printer was used to provide visual readout.

Scoring of the subjects began with session 3. Here, it became necessary to establish certain arbitrary rules. No attempt was made to force the subjects to learn mnemonic coding.* Instead, normal English words were keyed. The subjects were given a list of 300 three-letter words for transcription, and were told that they would be scored on the basis of the total

*Appendix A of this report tabulates suggested mnemonic coding for standard messages.

number of such words that they typed correctly during each session. Typing of this word list was required during sessions 3 thru 12, and again on sessions 20, 30, 39, and 40.

Learning curves for the individual subjects using the three different keyboards are depicted in Figures 4, 5, and 6, and indicate the rapidity with which facility in keyboard usage was acquired. For the subjects using the 4 x 3 and 3 x 4 keyboards, all reached speeds equivalent to verbalization within six hours, and one subject accomplished this in 2 1/2 hours. By the end of this time, all subjects were essentially touch-typing, referring to their keyboard chart only occasionally for the more uncommon letters. The data for the modified Touchtone keyboard concept are unfortunately less complete, since one patient was discharged from the hospital before completing his series of sessions, and one corpsman dropped out pleading pressure of other work. Two of the subjects using this keyboard equalled verbalization speed within 4 1/2 hours; the third had not reached this speed at the end of six hours when he dropped out.

No correlation between typing proficiency and either age or educational level was noted. Figures 7 and 8 indicate this finding for a representative session, number 20.

Error rates for all subjects were reasonably low, ranging from 3 to 7%, an error in this case being scored for one or more letters incorrect in the three-letter word. As might be anticipated, error rates were somewhat higher for the faster typists.

It is dangerous to make broad generalizations from data based upon such a small number of experimental subjects, but certain trends are apparent. Entry of simple air-to-ground messages using a simple keyboard is feasible and can be competitive in speed with verbalization after only a few hours of practice. All three of the keyboards studied appear to be usable. The 4 x 3 and 3 x 4 matrix keyboards offer mnemonic coding possibilities not inherent in the modified touchtone keyboard, and require a smaller number of keys and less hand movement. Prior to the keyboard evaluation, it appeared possible that subjects using the 4 x 3 keyboard might have certain difficulties due to lack of training of the little finger, and for this reason the 3 x 4 layout was also evaluated as an alternative. Difficulties due to the use of the little finger were not evident during the keyboard evaluations, and the use of the 4 x 3 keyboard is recommended for future studies since no "hurdles" of one finger over intermediate keys is required for any of the combinations of the phonetic alphabet and only one letter, "G", requires successive operation of two different keys with the same finger, as opposed to five such combinations for the 3 x 4 key layout.

Caution should be exercised in assuming that airline personnel working under conditions of turbulence could use the keyboards with the same facility as the subjects of this experiment. Data obtained in a moving base aircraft simulator are required before extrapolating the present experimental results to the user situation.

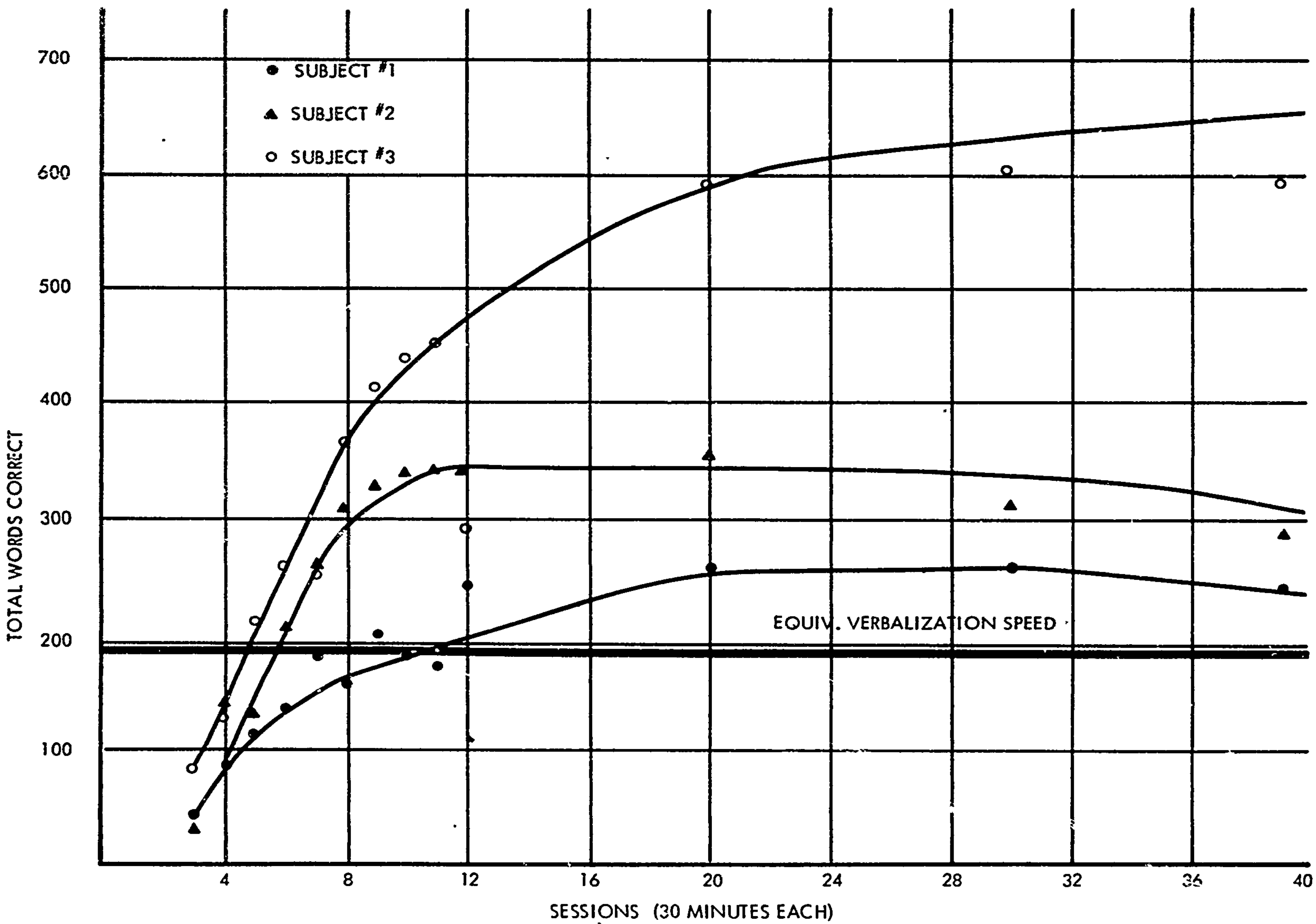


Figure 4. Exercise Using 4 x 3 Keyboard

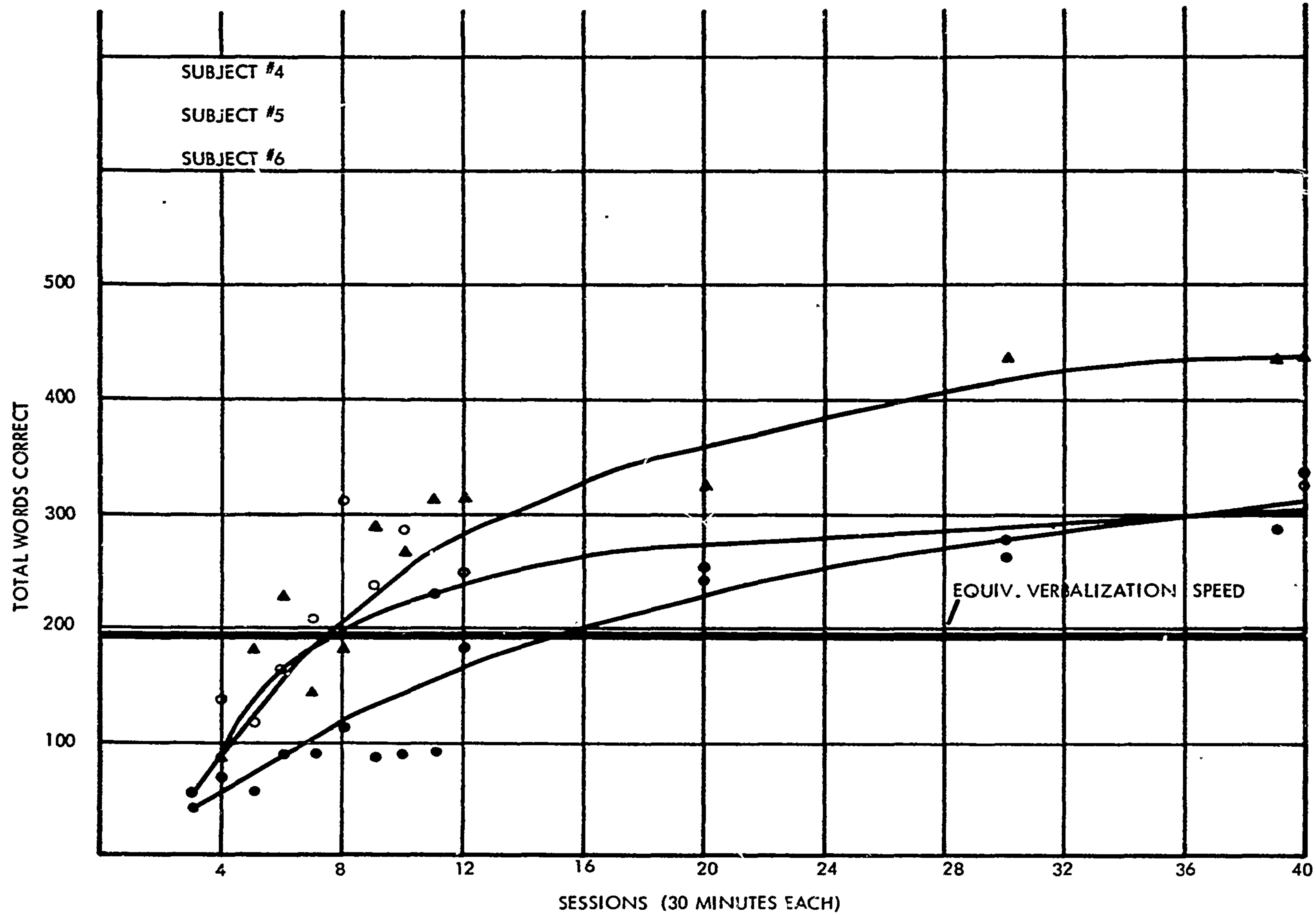


Figure 5. Exercise Using 3 x 4 Keyboard

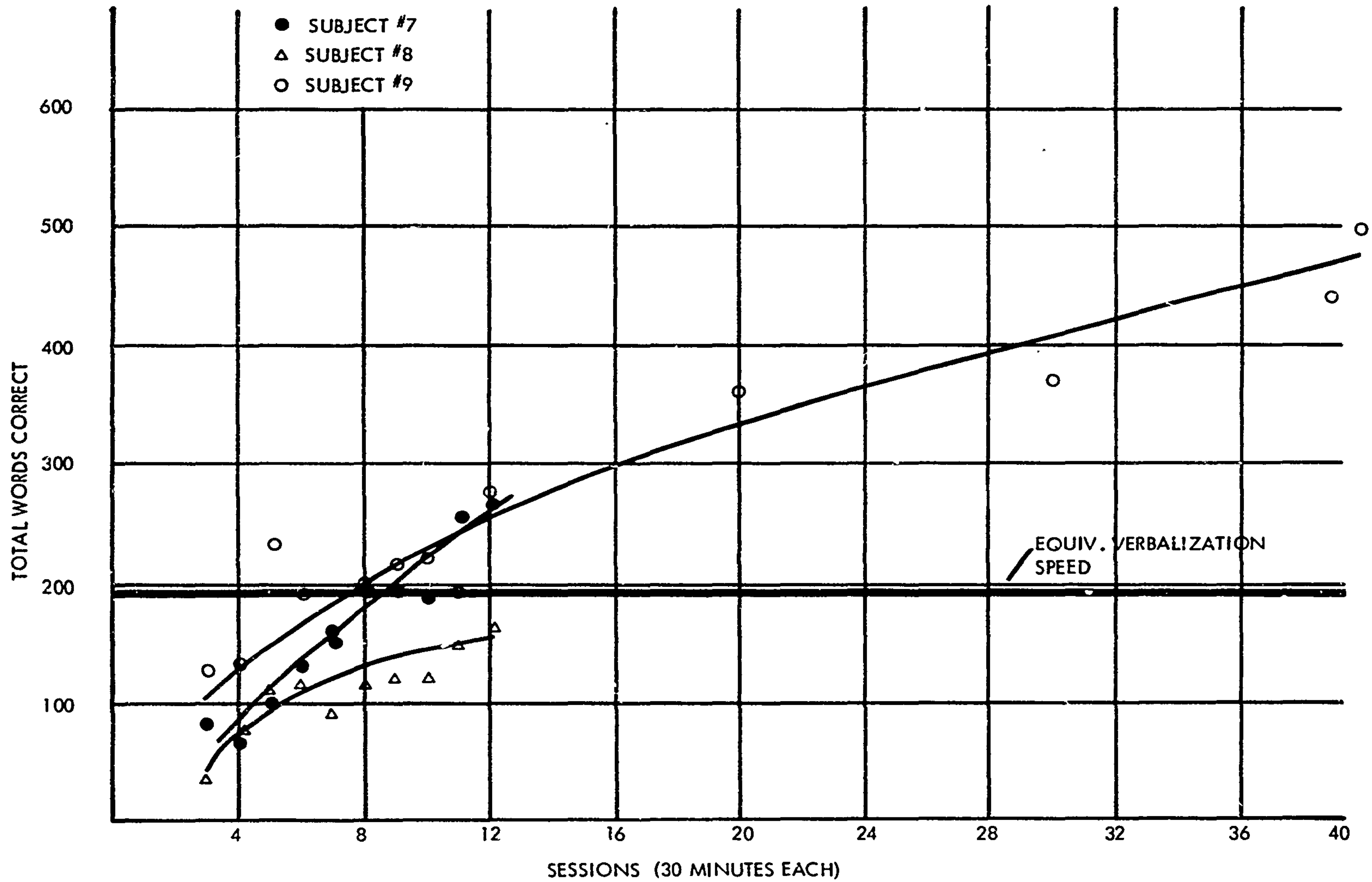


Figure 6. Exercise Using ARINC Keyboard

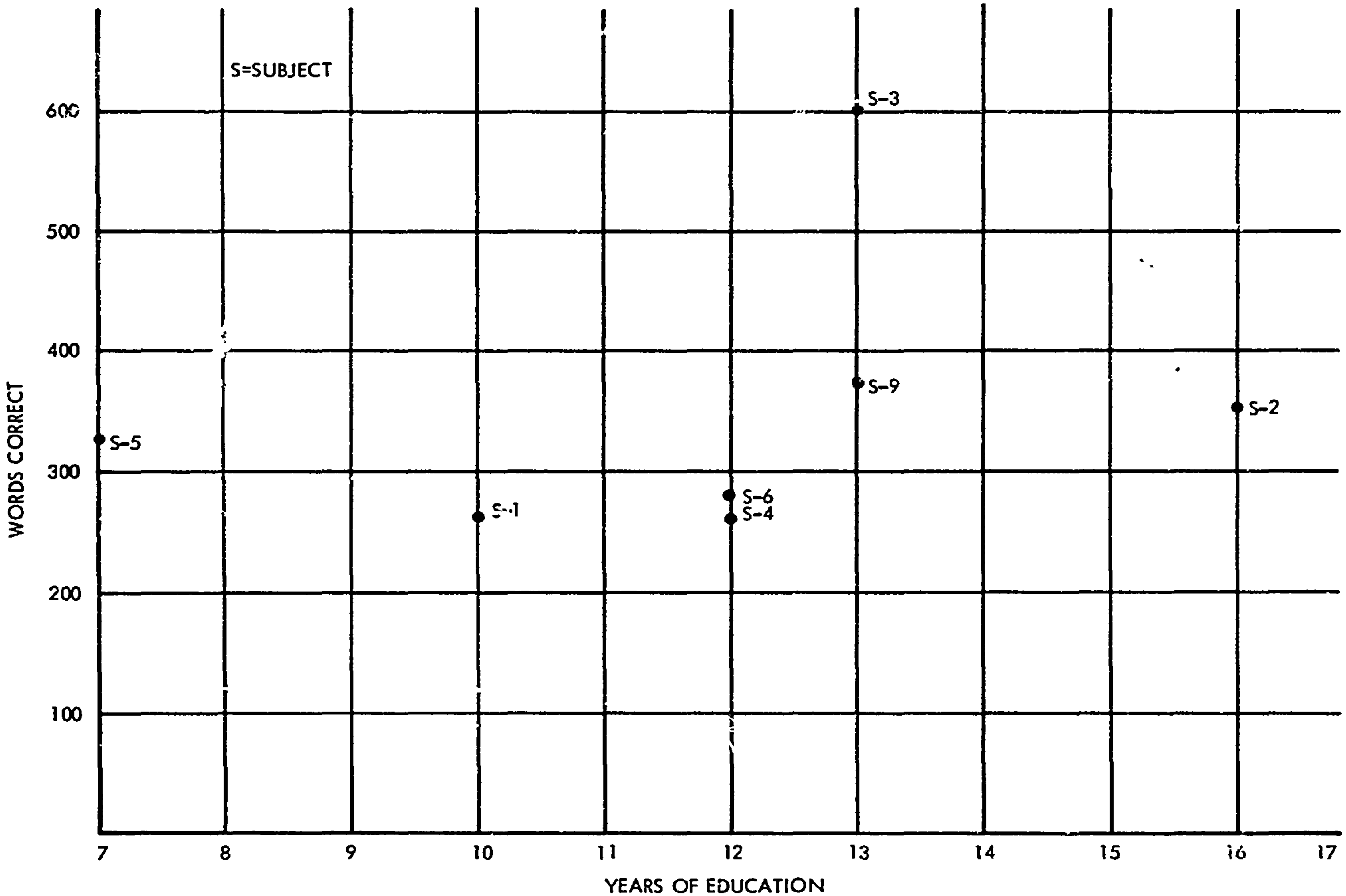


Figure 7. Scores on Sessions No. 20

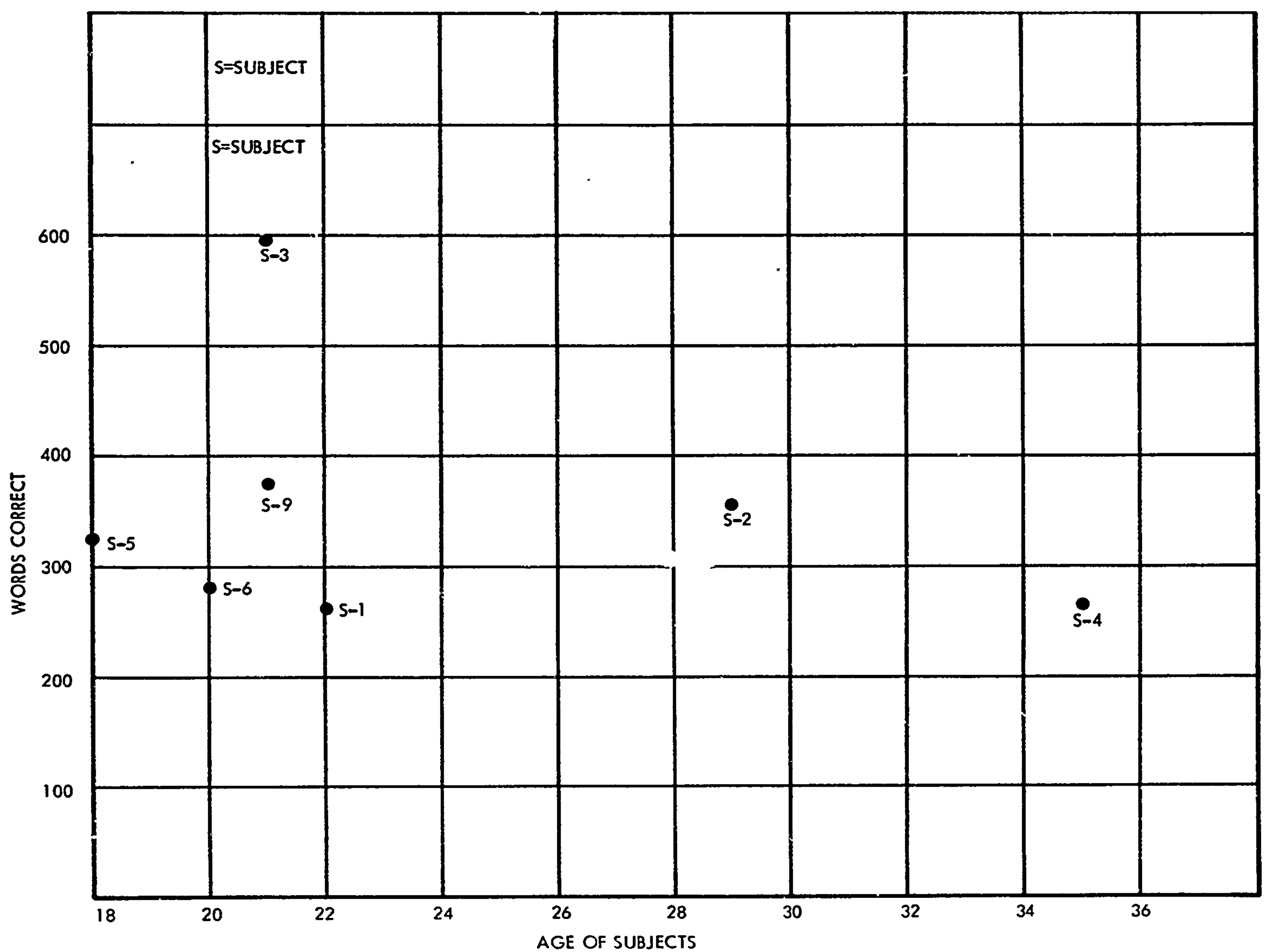


Figure 8. Scores on Session No. 20

APPENDIX
MESSAGE CODING SCHEME

A technical memorandum published midway through this project outlined a suggested rationale for the development of a group of standard air-ground-air messages mnemonically coded and requiring a minimum number of keystrokes for message insertion. Since that report was not widely distributed, this appendix repeats this material in essentially its original form.

"As mentioned previously, the keyboard suggested by ARINC in Data Link Newsletter #121 utilizes essentially the standard Bell Touchtone system, with added keys to permit selection of the right, center or left alpha indicated on the keys of the 10-key set. This keyboard thus requires the activation of two keys for each alpha selected. For the pilot, this does not impose a severe burden, since he is supplied with a list of 21 standard messages, each identifiable by a two-digit number (unless he loses or forgets these numeric equivalents). Only four of these standard messages are followed by a requirement for additional alpha designations. For the ground controller, the opposite situation exists. The messages for the most part are designed to fit a 7 or 14-character window display, and this could require 14 to as many as 28 key activations to generate a message unit.

Since a keyboard layout of this type is already familiar to telephone users, its use as a Data Link input device cannot immediately be discounted. At the same time, the requirement for double keying to select alphas justifies the exploration of other configurations and coding schemes which might be superior for use with the restricted vocabulary of the Data Link Application.

The ongoing analysis of message content of ATC communications does not indicate that a requirement for the designation of individual alphas occurs with high frequency, but such occasions arise. While a pilot in the Boston area is normally concerned with the weather at Logan Airport, others may at times request information concerning the weather at Providence or Bangor, and this would necessitate the input of specific alphas. To the extent that such information can be encoded without unduly increasing the complexity of the balance of the system, the inclusion of alpha capability should be provided.

Similarly for standard messages, it is obvious that training time can be reduced if mnemonic coding using key letters of words can be employed so that memorizing of numerical equivalents can be avoided.

Thirdly, but equally as important, the coding used should minimize the number of keyboard activations required to produce any standard message.

Fourthly, to the extent that pilots and ATC personnel are more familiar with certain specialized coding than is the general population, this should be incorporated if it can reduce training requirements.

The ICAO code represents an example of this last category, and effort has accordingly been directed toward using this as a part of an encoding scheme for Data Link. With proper selection of combinations of alphas on individual keys, the first two letters of the words used in the ICAO code can yield unique combinations. Since "foxtrot", "golf" and "hotel" all have the same second letter (and other similar situations occur with other letter combinations), the assignment of three sequential letters to each key in the manner of the Bell Touchtone Keyboard precludes this sort of coding. However, since airline pilots and ATC personnel are already completely familiar with this alphabetic representation, further exploration of the concept seemed warranted. For example, keys might be allocated as follows to yield non-redundant coding for individual alphas:

Key	Alphas	Numerical Equivalents
1	ABC	16, 18, 14
2	DEF	22, 21, 27
3	G	37
4	H	47
5	IJK	57, 59, 55
6	L	65
7	MNO	75, 77, 78
8	PQRS	81, 89, 87, 85
9	TVU	91, 97, 95
0	WXYZ	04, 08, 01, 09

It should be pointed out here that these letter-numeric combinations for coding purposes are completely independent of keyboard layout, and are equally useful with either the 4 x 3 or 3 x 4 matrices discussed earlier.

The coding scheme used above immediately permits the elimination of the three keys required in the ARINC concept for specification of "right", "center" and "left"; permits the generation of any unique alpha without increasing the number of key activations required over that of the ARINC concept, and permits a more compact keyboard, with resulting decrease in the requirements for hand travel.

The above thus utilizes 26 of the 100 possible two-digit combinations as follows:

Second Digit

First Digit	0	1	2	3	4	5	6	7	8	9
0		X			X				X	X
1					X		X			
2		X	X					X		
3								X		
4								X		
5						X		X		X
6						X				
7						X		X	X	
8		X				X		X		X
9		X				X		X		

By the use of reasonably simple digital logic, it is possible to specify that each of these two-digit combinations should result in the appearance and later transmission of a single alpha. However, by utilizing similar logic, other unique two-digit combinations can result in the appearance of two alphas which can be useful in a mnemonic coding scheme. Thus, by using the following, standard messages may be encoded without too great departure from the vocabulary presently in use. For example:

Characters Ground to Air	Air to Ground
02 - WEather (provides automatic transmission of weather information.*	Request for WEather info.
05 = WK squaWK ident. (May be followed by a numeric code).	Not used
07 = YM You May (permission granted).	Not used
10 = CW Contact Wide area control (ARTCC).	Not used

*As a minimum, altimeter setting should be provided. However, with the greater transmission efficiency of data link, a canned message could be transmitted including wind speed and direction, RVR, and runway conditions such as icing. Not all of this can presently be provided to every aircraft during peak traffic periods.

Characters Ground to Air	Air to Ground
11 = CA Contact Approach control	Not used
12 = CD Contact Departure control	Not used
13 = CG Contact Ground control	Not used
15 = AK AcKnowledge(ment)	AcKnowledge(ment)
19 = CT Contact Tower	Not used. Or this may be a request for the frequency if it is not automatically supplied by the ground
25 = DI Dump Information (means for clearing the display) [Not a transmitted message] or transfer to another controller)	
26 = FL Flight Level? (Request for altitude information)	Not used in two-character format
28 = ER Not used	Emergency Request for priority in use of voice channel
34 = GH Not used	may I Go Higher? (request for a higher altitude)
36 = GL Not used	may I Go Lower? (request for a lower altitude)
46 = HL Hold Level (maintain present altitude	Holding present Level (might be followed by digits to indicate reaching a requested altitude)
49 = HT Hold after Taxiing	Holding after Taxiing
51 = IC Not used	Initial Contact with a new controller. (should automatically provide flight #, aircraft type and other pertinent info.)
52 = IF If Feasible	If Feasible

Characters Ground to Air	Air to Ground
56 = IL I Locate you (radar contact)	I Locate the traffic you have pointed out
62 = LE LEave a hold or restriction	LEaving (rolling, taking off, departing, etc.)
67 = LM Lost Message (Request for retransmission)	Lost Message (Request for retransmission)
68 = LS What is your Lowest Speed possible?	Not used in two-character format
71 = NC You are Now Cleared	Not used
76 = NL Not Located (can't find you on radar)	traffic Not Located
79 = OU Not used in two-character format	report of reaching the OUter marker
80 = SW Stay With me (remain on this frequency	Not used
83 = RG Restriction Gone (lifted)	Not used
90 = TY Thank You	Thank You
92 = TD Not used in two-character format	estimated Traffic Delay requested
99 = TU TUrbulence (possible from wake of previous aircraft.	TUrbulence report.

For standard messages, the above permits their generation by the actuation of only two keys and using an easily remembered coding scheme.

A few words may be in order concerning the use of "AK" for acknowledgement. With present voice transmissions, any commands or advisories from the ground are repeated by the pilot to assure the accuracy of reception. With Data Link, "AK" could cause automatic retransmission and automatic parity check against the original transmission. This could have a major impact on present procedures. At present, transactions are possible with only one aircraft at a time. With appropriate display to a controller that parity had been achieved and that the acknowledgement had not been delayed more than a few seconds, the busy controller could turn his attention to a second aircraft even before the receipt of acknowledgement from the first.

A number of the standard messages require subsequent transmission of digits. This should be accomplished by an automatic shift when the decoding logic recognizes these particular combinations. Such messages include:

Characters Ground to Air	Air to Ground
17 = AM AltiMeter setting is XXXX	Not used
26 = FL Not used in this format	Flight Level is XXX
39 = GT Go To (altitude XXX)	Going To (altitude) XXX
41 = HA Hold at Altitude XXX	Holding Altitude XXX
44 = HH Hold Heading XXX	Holding Heading XXX
48 = HS Hold Speed at XXX	Holding Speed at XXX
58 = IS Increase Speed to XXX	Increasing Speed to XXX
68 = LS Not used in this format	Lowest Speed possible is XXX
69 = LT Locate Traffic at XXX	Not used in this format
79 = OU OUter marker is XX miles	Not used in this format
82 = SD Slow Down to XXX knots	Slowing Down to XXX knots
86 = RL Report at Level (alt) XXX	Reporting at Level XXX
92 = TD Traffic Delay estimate is XX	Not used in this format

Characters Ground to Air	Air to Ground
96 = TL Turn Left to XXX heading	Turning Left to XXX heading
98 = TR Turn Right to XXX heading	Turning Right to XXX heading

For standard messages, the requirement for subsequent alpha designations does not seem to occur with any great degree of regularity. Possible examples include:

29 = ET Continue Enroute To XXX (fix)	Reporting Enroute To XXX (fix)

42 = HF Hold at Fix XXX
(426 = left turns: 428 = right turns).

The inclusion of specific alpha capabilities does, however, permit modification of standard messages. Thus, using the earlier example, a plane in the Boston area normally is concerned with the WEather at BOS, and the BOS designation should not be required in this case. If, however, he desires WEather information at Providence, he might inquire from the Boston tower concerning "WE-PApa VIctor DElta".

Although drastic maneuvers for collision avoidance fortunately are not required with any great frequency, it seems important to allocate certain combinations for this purpose, and to make these allocations such that the input requirement is as rapid and unambiguous as possible. With this in mind, the combinations 33 (fly up), 66 (fly left), 88 (fly right) and 00 (dive) have been reserved. The location of these keys in the matrix is indicative of the direction of the required maneuver, and for the 4 x 3 matrix, the arrangement is symmetric. It is further suggested that to avoid inadvertent transmission of a false alarm, these messages should require that the reserved keys should be activated more than twice, and within a specified total time period.

Since all of the standard messages started with alphas, but may end with numerics, a dash or space key should be provided to permit the generation of multiple message units. In this case, this key would serve as an automatic shift key to return to alphas for the start of the next message unit.

Furthermore, because the messages are so short, it does not seem necessary to include a backspace key. Instead, when an entry error is made, the cancel key should eliminate the entire message, or the portion of the message back to the previous dash.

The system, at its present stage of evolution, is utilizing the following combinations without redundancy:

First Digit	Second Digit: 0	1	2	3	4	5	6	7	8	9
0	X	X	X		X	X		X	X	X
1	X	X	X	X	X	X	X	X	X	X
2		X	X			X	X	X	X	X
3				X	X		X	X		X
4			X		X		X	X	X	X
5		X	X			X	X	X	X	X
6			X			X	X	X	X	
7		X				X	X	X	X	X
8	X	X	X	X		X	X	X	X	X
9	X	X	X			X	X	X	X	

The blanks in the above indicate that there is system growth potential. More probably, the changes which occur will not be so much in the matter of growth of the number of messages used, but rather in identifying the most useful messages and improving their mnemonic coding to avoid some of the liberties taken here by departing from presently used ATC vocabulary. Suggestions in this direction would be welcomed. Additionally, useful and non-redundant codes for a few additional frequently used terms such as RVR and Runway in Use would be desirable, although both of these particular examples could be routinely supplied as part of a canned transmission of WEather information.

The previous listing of message types in numerical order, while it demonstrates that non-redundant coding has been achieved, may be somewhat confusing. In the listing below, messages are therefore grouped according to general categories:

ALTITUDE: Maintain (46); Change to (39); Report Reaching (86); Present altitude info. or request (26).

HEADING: Maintain (44); Turn right to (98); Turn left to (96).

SPEED: Maintain (48); Increase to (58); Decrease to (82); Lowest possible speed (68).

COLLISION AVOIDANCE: Fly up (33333); Dive (00000); Sharp Right (88888); Sharp Left (66666).

RADIO FREQUENCY CONTROL: Contact Approach Control (11); Contact Departure Control (12); Contact Ground Control (13); Contact Tower (19); Contact ARTCC (10); Remain on present frequency (80).

RESTRICTIONS AND CLEARANCES: Hold at fix (42); Taxi & hold (49); Clearance (71); Restriction lifted (83); Leave (62); Permission granted (07); Continue en route to (29).

RADAR: Radar contact (56); No radar contact (76); Squawk ident. (05).

ADVISORIES: Weather (02); Possible turlulence (99); Other aircraft (69); Estimated approach delay (92); Outer marker (79).

MISCELLANEOUS: Acknowledge(ment) (15); If feasible (52); Thank you (90); Retransmission request (67)."

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